Norwegian Shelf

based on the article *Identification and characterization of internal waves in SAR images along the coast of Norway* by S. T. Dokken, R. Olsen, T. Wahl, and M. V. Tantillo [2001] with permission of the authors

Overview

The Norwegian Shelf extends off the west coast of Norway from roughly 61° to 71°N (Figure 1). The Norwegian current flows north along the edge of the Shelf. The shelf is also connected to the Iceland-Faroe Ridge that separates the Arctic water in the Norwegian Sea from the warmer waters of the North Atlantic [LME 2004].

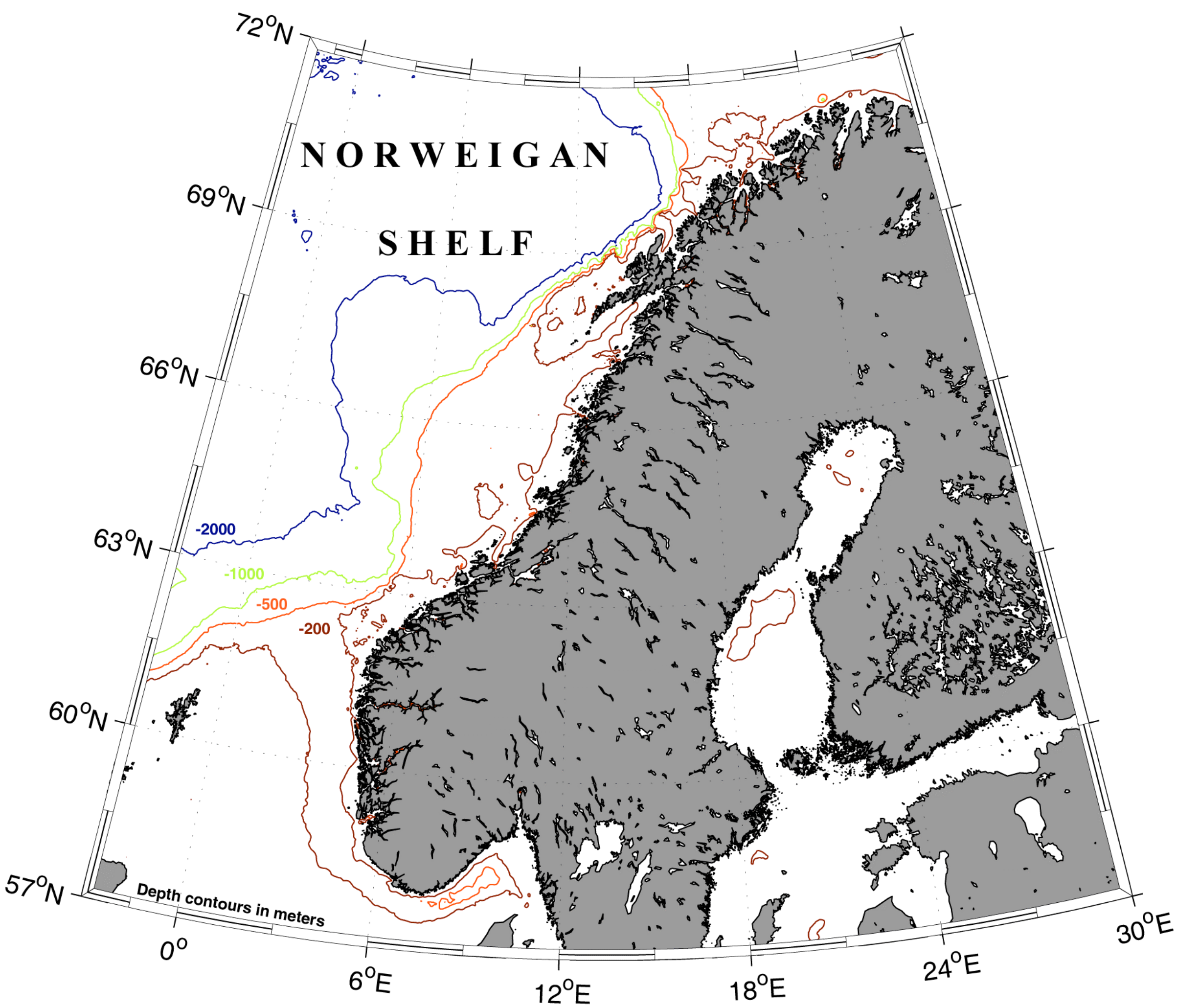


Figure 1. Bathymetry of the Norwegian Shelf. [Smith and Sandwell, 1997]

Observations

Internal wave activity along the Norwegian Shelf occurs mainly in four "hot-spot" areas each with distinctive characteristic. These areas include Egga, Moskenes, the Vøring plateau, and the Norwegian Trench. The internal waves occur most frequently in the late summer, when thermal stratification is most pronounced and wind conditions are moderate.

The Norwegian Defense Research Establishment (FFI) has acquired more than 2600 ERS-1 and ERS-2 Low Resolution Images (LRI) and RADARSAT-1 ScanSAR Wide images from the Tromsø Satellite Station from the period 1991 to 2000. The data set was not randomly obtained but contains samples from almost the entire coastline. One hundred thirty six (136) out of 2600 SAR images (i.e. 5 percent) contained internal wave signatures. Figure 2 shows the monthly absolute and relative (as compared to the number of acquired SAR images) temporal distribution of internal waves. The annual variation is exemplified for the years 1991-1995 versus 1996-2000.

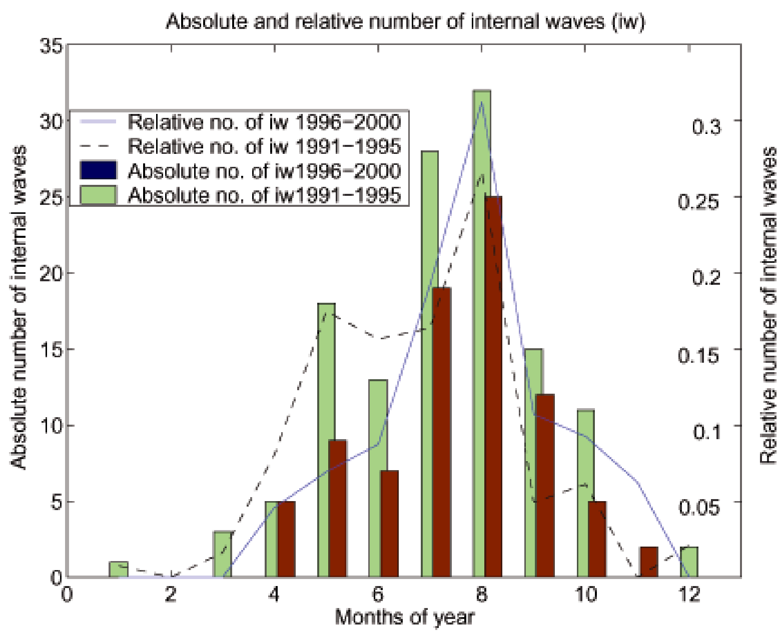


Figure 2 Months when Internal Waves have been observed along the Norwegian Shelf

The typical internal wave train found in SAR images from Norwegian waters is 11 km wide and contains 4 wave crests (but a maximum of 11 wave crests has been observed). It is 2.24 km long with a leading intersoliton distance of 900m. Its propagation speed is approximately 0.5 m/s, and the originating location and progression can, in most cases, be estimated using a bathymetric and a tidal amplitude map. Eighty eight percent of the observed internal waves have been detected within the 4 "hot-spot" areas along the Norwegian coast. Table 1 presents the breakdown of wave occurrence by site and season. The site characteristics are:

Egga: The tidal flow against the steep shelf break outside Andøya, where the deep ocean nearly touches mainland Norway, generates numerous internal waves propagating Westwards and Southwards. Simultaneous wave trains associated with more than one tidal cycle are frequently observed. (Figures 3 and 4)

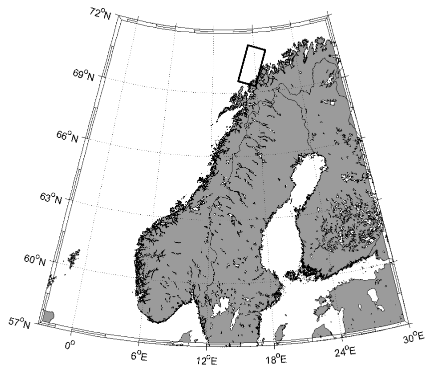
Moskenes: The strong tidal current called the Maelstrøm resides in the Moskenes Sound, located in Lofoten between Moskenesøy and Værøy [*Gjevik et al.,* 1997]. The tidal flow can be characterized into eight different cases [*Dokken and Wahl*, 1996], and the 1/2 low and 3/4 low tide situations generate westward propagating internal waves when the outgoing jet from the Moskenes sound is deflected towards North. Observations and laboratory experiments [*McClimans*, 1997] substantiate that internal waves cannot be sustained at the eastern part of the Moskenes Sound because of tidal destruction of the ocean stratification. The average middle tide height difference for the area is 174 cm per year [*Nordanger Forlag*, 1995]. (Figures 5 and 6)

The Vøring plateau: Located at a depth of 1300m, the almost circular shaped Vøring plateau generates internal waves with small front curvatures in the summer season all around the plateau's edges. (Figure 7)

The Norwegian Trench: The internal waves propagate in the Northeast direction along the edges of the end of the Norwegian Trench (i.e. Vestfold). They are observed to be dispersive, having a small front curvature, though quite irregularly shaped. They are believed to be tidally generated, although the tidal amplitude is low in this area (typically 20 cm) [*Nordanger Forlag*, 1995]. The tidal flow is assumed to influence the stability of the pycnocline above the trench's slopes, and thereby generate the internal waves. This explains the higher temporal occurrence in the summer months associated with a stronger pycnocline, although the SAR internal wave manifestations are reduced in stormy and turbulent winter weather. (See the case study of the North Sea). The beginning of the trench (i.e. Hordaland) frequently generates dispersive internal waves with relatively large front curvatures.

Location	**Number observed**	**Season (%);** **spring-summer-autumn-winter**	**Dispersivity (%): yes-little-no**
The Norwegian Trench:	64	28-48-20-4	68-29-3
Start	25	32-60-4-4	80-20-0
End	35	20-43-34-3	60-37-3
Vøring	21	0-100-0-0	65-35-0
Moskenes	11	0-82-18-0	0-100-0
Egga	62	13-50-35-2	79-21-0
Elsewhere	31	16-45-32-7	50-50-0

Table 1: The location of detected internal waves along the coast of Norway.



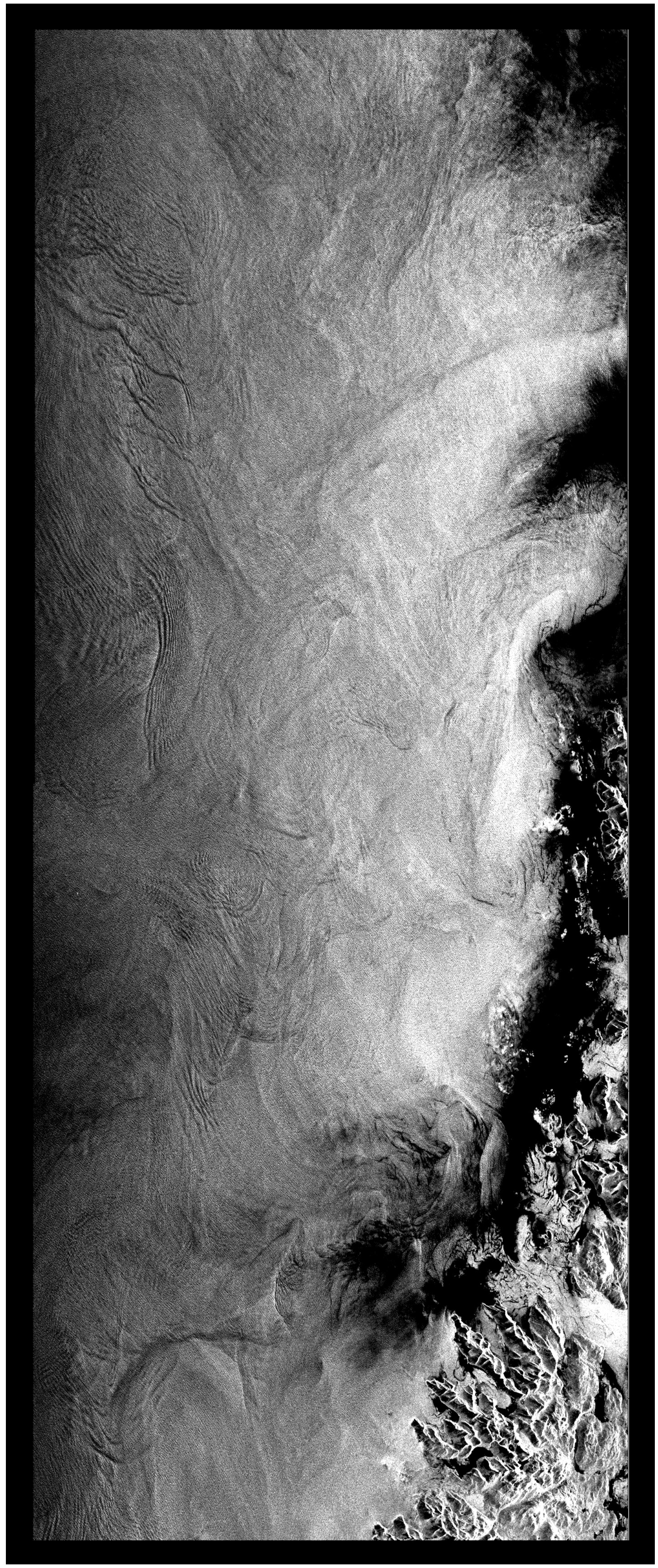


Figure 3. ERS-2 (C-band, VV) SAR image over the Northern Norwegian Shelf acquired on 9 September 1997 at 1024 UTC. The image shows a large number of waves, the majority of which are propagating southwest parallel to the coast. Imaged area is 100 km x 200 km. ©ESA 1997. [Image courtesy of Richard Olsen Norwegian Defense Research Establishment (FFI), Department of Electronics, Norway.]

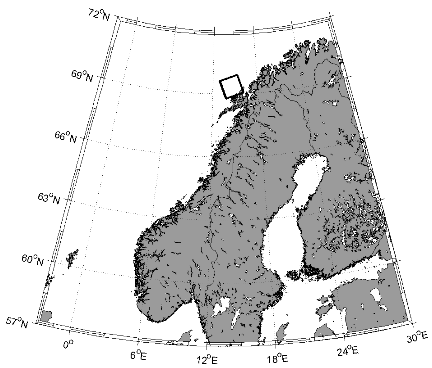
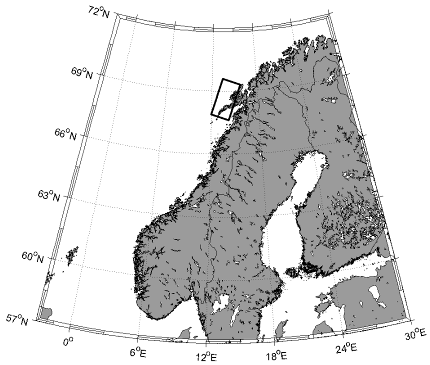


Figure 4. ERS-2 (C-band, VV) SAR image in the Egga area near Andøya acquired on 10 July 1997 at 1041 UTC. The image shows a variety of wave signatures propagating in different directions. Imaged area is 100 km x 100 km. ©ESA 1997. [Image courtesy of Richard Olsen Norwegian Defense Research Establishment (FFI), Department of Electronics, Norway.]



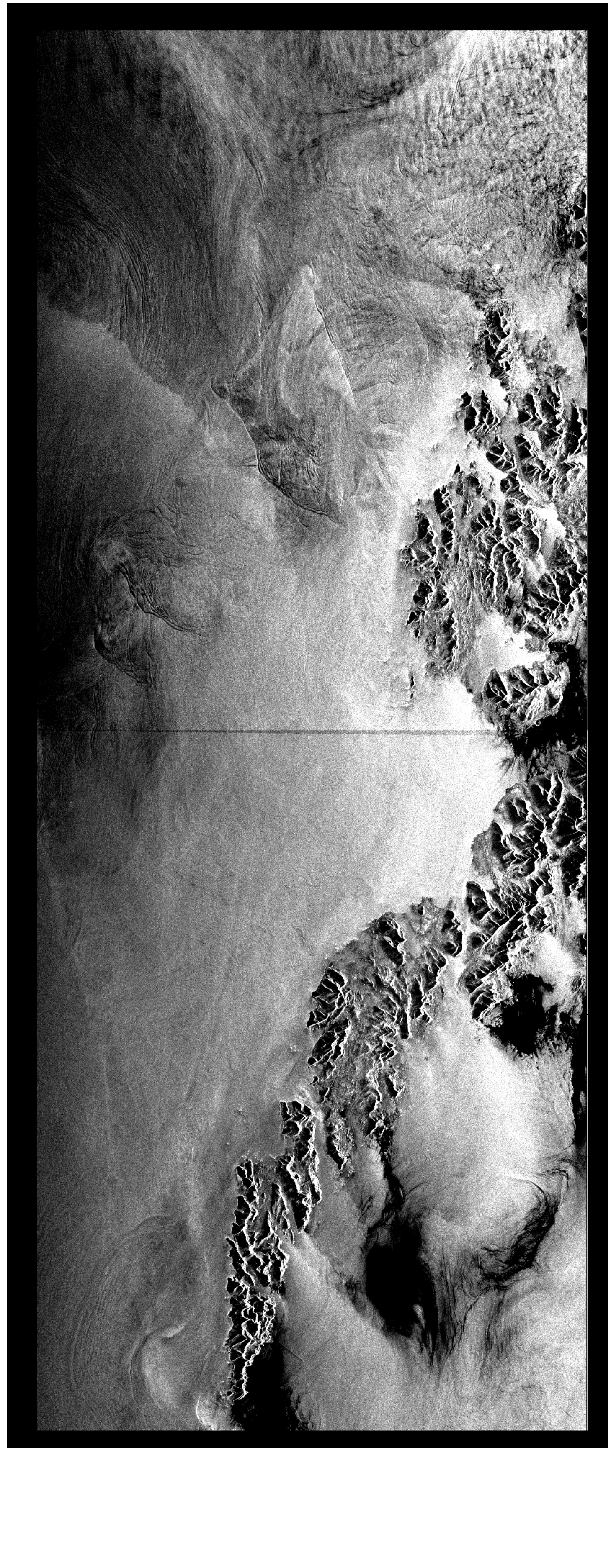


Figure 5. ERS-2 (C-band, VV) SAR image in the area between Egga and Moskenes acquired on 18 June 1997 at 1033 UTC. The upper half of the image shows internal wave signatures propagating parallel to the coast in addition to current signatures. Near Mokenes (lower left) several packets can be seen propagating away from shore. Imaged area is 100 km x 200 km. ©ESA 1997. [Image courtesy of Richard Olsen Norwegian Defense Research Establishment (FFI), Department of Electronics, Norway.]

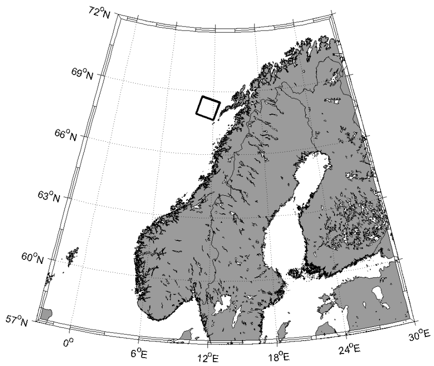


Figure 6. ERS-2 (C-band, VV) SAR image in the area off Moskenes acquired on 30 August 1997 at 2031 UTC. The image shows internal wave signatures propagating parallel to the coast (lower left quadrant). Current, slick and atmospheric signatures are also visible. Imaged area is 100 km x 100 km. ©ESA 1997. [Image courtesy of Richard Olsen Norwegian Defense Research Establishment (FFI), Department of Electronics, Norway.]

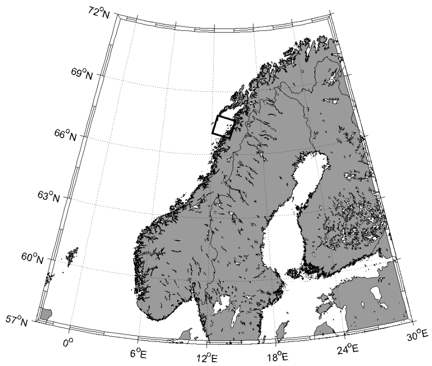
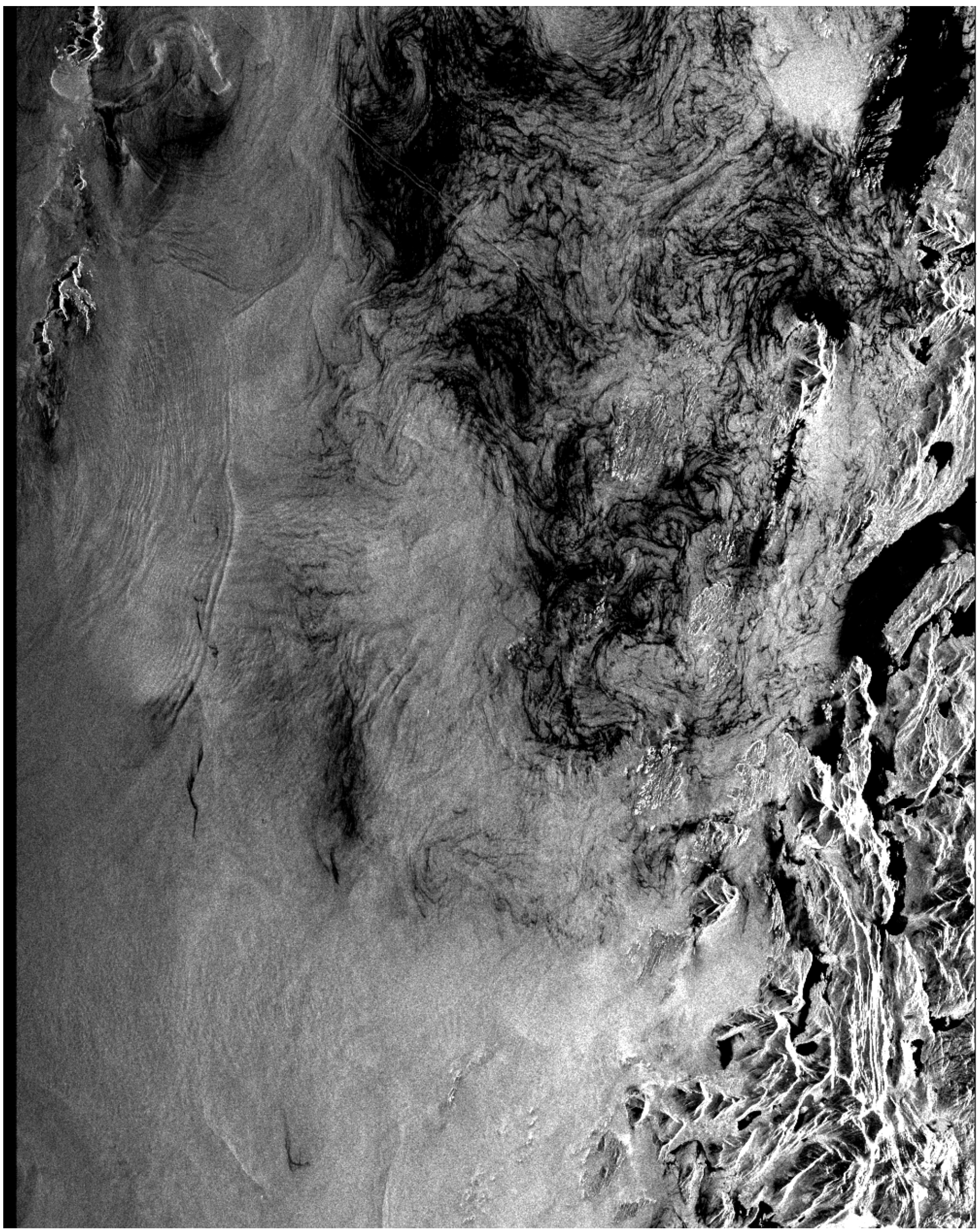


Figure 7. ERS-2 (C-band, VV) SAR image over the Vøring plateau acquired on 4 July 1997 at 1031 UTC. The image shows several internal wave packet signatures propagating toward the coast. Biological slick show small scale eddies and other surface dynamics. Imaged area is 100 km x 100 km. ©ESA 1997. [Image courtesy of Richard Olsen Norwegian Defense Research Establishment (FFI), Department of Electronics, Norway.]



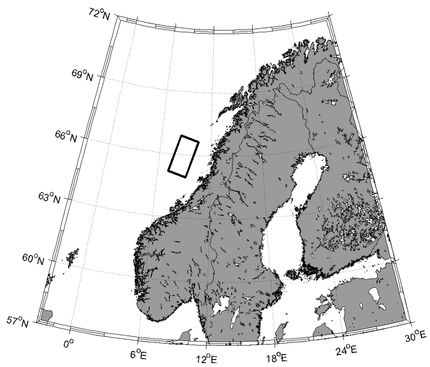


Figure 8. ERS-2 (C-band, VV) SAR image over the open on the Norwegian Shelf acquired on 9 June 1998 at 1045 UTC. The image shows a variety of internal signatures and propagation directions. Imaged area is 100 km x 200 km. ©ESA 1998. [Image courtesy of Richard Olsen Norwegian Defense Research Establishment (FFI), Department of Electronics, Norway.]

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